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UNITED STATES AIR FORCE

School of AVIATION MEDICINE

EFFECTS OF EXTREME HEAT ON MAN

IV. MECHANISM OF HEAT TRANSFER IN AN OPEN GASOLINE FIRE

PROJECT NUMBER 21-26-002
REPORT NUMBER 4

PROJECT REPORT

USAF School of Aviation Medicine, Project No. 21-26-002, Report No. 4.

Effects of Extreme Heat on Man: IV. Mechanism of Heat Transfer in an Open Gasoline Fire.

Konrad Buettner, Everett O. Richey, USAF School of Aviation Medicine, Randolph Field, Texas.

4 pp & ii. 2 illus. 27 cm. UNCLASSIFIED

The heat transfer to a body suspended in an open gasoline fire was measured using calorimeters with black and with highly polished metallic surfaces. In all but one fire at least 90 percent of the heat transfer occurred by radiation. This radiation was reduced markedly by a highly polished metallic surface until the surface was blackened by soot. The blackening occurred gradually during the first 50 seconds after entry into the flame.

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Department of Radiobiology

PROJECT NUMBER 21-26-002
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USAF SCHOOL OF AVIATION MEDICINE
RANDOLPH FIELD, TEXAS

JULY 1951

PRECIS

OBJECT:

To study the process of heat transfer inside a gasoline fire.

SUMMARY AND CONCLUSIONS:

With a simple calorimeter in an open gasoline fire the heat transfer from the fire to a black surface and to a shiny metallic surface was measured. The transfer of heat occurred almost exclusively by radiation. During the first 50 seconds the transfer of heat to a polished aluminum surface was markedly lower than to a black surface. After this time the polished surface was so blackened by soot that it acted, essentially, as a black body.

In close proximity to a gasoline fire, polished aluminum surfaces reflected more than 90 percent of the radiant heat which would normally be absorbed (1,2). This reflection decreased to that of a black body in approximately 50 seconds after entry into the actual flame of the fire.

RECOMMENDATIONS:

1. Fire-fighting suits should be provided with a surface which will reflect radiant heat.

2. Studies should be directed toward cause and prevention of soot deposit on reflecting surfaces.

MECHANISM OF HEAT TRANSFER IN AN OPEN GASOLINE FIRE

INTRODUCTION

One of the major problems encountered in rescuing personnel from burning aircraft is protection for the rescue worker while in the fire. The mechanism of heat transfer within a fire should be evaluated in order to obtain data useful in redesigning present fire-fighting suits.

Heat transfer from a flame to a body within the flame is effected by convection and radiation. A black body is a good absorber and a shiny metallic body is a good reflector of radiant heat. If their size, shape, and material are similar, however, they have the same convection characteristics. This being the case, two bodies of the same size, shape, and material but with dissimilar surfaces (i.e., one with a black surface and the other with a reflecting surface) should have different rates of temperature increase when placed in a fire, since the black body will receive heat by both the convective and radiative processes while the reflecting body will receive heat by the convective process only. The difference in the rates of temperature increase will be a measure of the relative amount of heat transferred by convection and by radiation.

CALORIMETER AND FIRE PROCEDURE

To measure the heat transfer in the flame of a gasoline fire a simple calorimeter (a piece of metal of known heat capacity) was placed in the flame and the rate of temperature increase measured. Four such calorimeters, aluminum cylinders 17 cm. long and 6.3 cm. in diameter, were used. A hole 3.8 cm. in diameter and 12 cm. deep was drilled along the longitudinal axis of each cylinder. Two of the calorimeters were painted black and the other two were polished to give them a shiny reflecting surface.

For measuring the various temperatures, iron-constantan thermocouples were made from wires 1.6 mm. in diameter. The thermocouple measuring the flame temperature consisted of .5 cm. of this wire bared, twisted, and silver-soldered, whereas thermocouples recording the temperatures of the four calorimeters consisted of 6 cm. of the iron-constantan wire bared, twisted, and soldered with ordinary lead solder. A thermocouple was attached with a screw to the bottom of the hole drilled in each cylinder. To prevent heat conduction along the wire to the thermocouple the hole was filled with solder to a depth of 4 cm., and approximately 6 m. of wire were wound in a tight spiral inside the hole and held in place with a quick-setting dental plaster.

The thermocouples were connected to two Brown ElectroniK Potentiometers. Since these are a null-balancing type of instrument, differences in the resistance of the lead wires did not affect the accuracy. One instrument recorded the flame temperature continuously on a 0-1,000° C. scale, while on the other the temperatures of the four cylinders were printed successively on a 0-500° C. scale with a time interval of 1 to 2 seconds between prints. Both instruments had a chart speed of 5.5 cm. per minute and an adaptation speed of 200° C. and 100° C. per second, respectively, which was much greater than the rate of temperature change of the thermocouples.

Three fires were made in a flat iron pan, 1 by 1.5 m. in size and 15 cm. deep, using 9.5 liters of gasoline for each fire. Two fires were made in an open dirt pit using 210 liters of gasoline for each. One of the tests was made during a period of absolute calm; the others were made during periods when the wind was less than 4 m. per second (approximately 10 miles per hour). The calorimeters were suspended from an iron rod so as to remain vertical throughout the fire. The bottoms of the calorimeters were 25 cm. above the level of the gasoline since this distance marked the point of the most dense and uniform flame. The thermocouple used to measure the flame temperature was fastened in the middle of the cluster of calorimeters on a level with the middle of the calorimeters.

In three fires the cylinders were in place before the fire was started; in the other two fires they were suspended from a movable iron pipe and placed in the flame after the fires were fully ablaze.

In another series of tests an electric furnace was used, to provide controlled conditions for studying the transfer of heat to the cylinders. After the furnace had stabilized at the desired temperature, the cylinders were inserted and their temperatures recorded.

RESULTS

The flame temperatures, as recorded by the free thermocouple, rose exponentially to a peak value in about 30 seconds. Analysis of this curve and comparison with known heat transfer data show that the exponential rise is due to the heat capacity of the couple and not to a lag in the temperature rise of the flame. There was no observable difference in the temperature increase curves of either the calorimeters or the free thermocouple regardless of whether they were in the flame from the moment of ignition or inserted after the fire had reached maturity. The flame temperatures ranged from 640° to 800° C. and showed irregular fluctuations caused by wind and convective turbulence.

The temperature of the cylinders displayed an average rise of 1° to 2° C. per second, depending on the surface and the flame temperature (see figure 1). During the first minute the temperature rise of the shiny cylinder was less than that of the black cylinder. After this period the two temperature curves were parallel; this indicated that the shiny surface had been covered by soot and was acting as a black body.

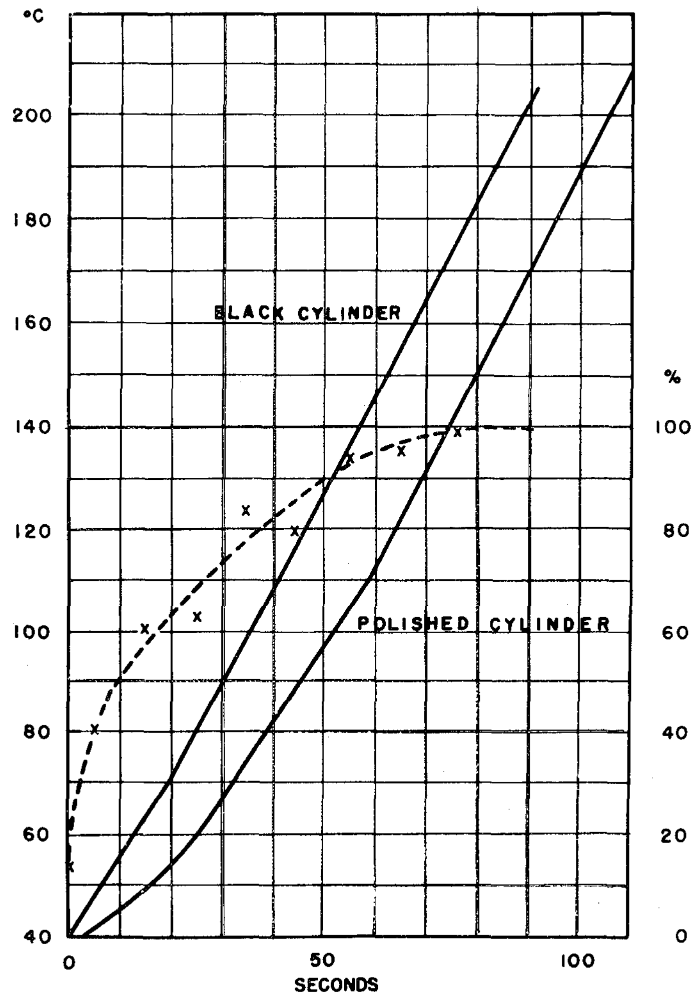

FIGURE 1

Increase in temperature of two aluminum cylinders in an open gasoline fire (fire No. 2, 10 October 1950, using 2.5 gallons ethyl gasoline in an open pan). The flame temperature varied between 620° and 750° C., with an average temperature of 700° C. The dashed curve is the ratio of the rate of temperature increase of the polished cylinder to the black cylinder.

CALCULATIONS

The standard equation for the transfer of heat to an object is

$$\frac{mc}{f}\frac{dT_c}{dt} = e\,\sigma\,(T_a^4 - T_c^4) + h\,(T_a - T_c) \qquad (1)$$

where

T_a and T_c = absolute temperature of ambient air and cylinder

m = mass of cylinder plus thermocouple (1.17 kg)

c = specific heat of cylinder (0.217 kg-cal/kg °K)

f = surface area (0.0380 m^2)

e = specific absorption for radiation concerned

σ = 4.96×10^{-8} kg-cal/m^2 hr °K^4

t = time

h = convective heat transfer coefficient (kg-cal/m^2 hr °K)

It has been previously established that for a black object the value of the specific absorption e is 0.9 or more. The specific absorption

of the shiny cylinder was measured by placing both cylinders in front of the open mouth of an electric furnace with a stable temperature of 600° C. and measuring their temperature increase. By substituting these values in equation 1, it was calculated that for the shiny cylinders (polished cast aluminum) used in this experiment the specific absorption e was 0.16.

If we assume a value of specific absorption e of 0.9 and a convection heat transfer for a sphere of 12 cm. diameter, with wind conditions of calm, 1 m. per second (approximately 2.24

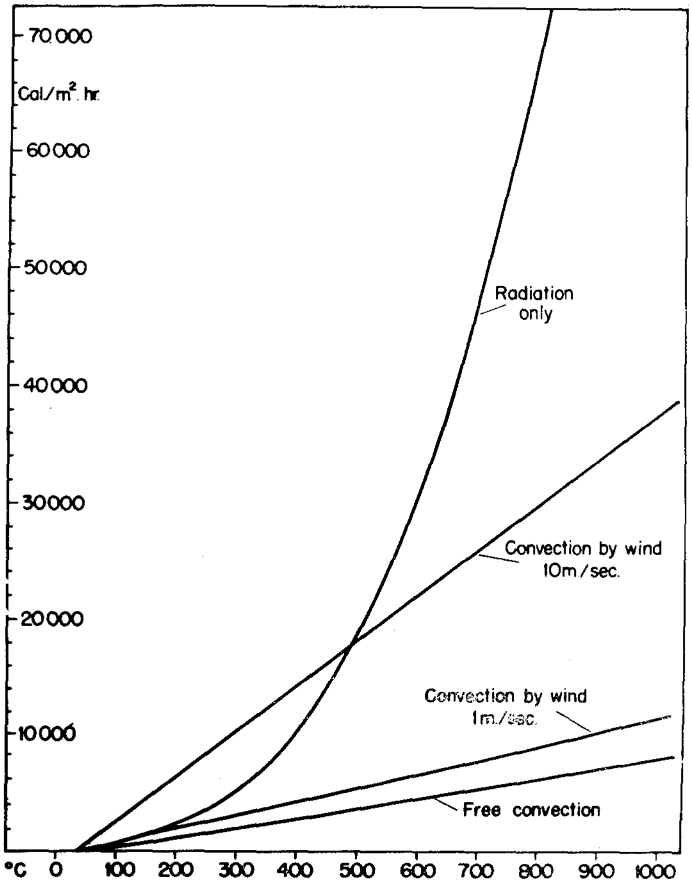

FIGURE 2

Heat transfer by radiation and by convection, respectively, at different environment temperatures. Data indicate heat flowing onto the surface of the human body at 37° C.

miles per hour) and 10 m. per second (approximately 22.4 miles per hour), then the rate of heat transfer for radiation and for convection is as shown in figure 2. (See also reference 1.)

Figure 2 shows that, for a temperature of 600° C. or more, the heat transfer by radiation is much greater than the heat transfer by convection. This being the case, the last term in equation 1 becomes negligible and the equation can be written as

$$\frac{mc}{f}\,\frac{dT_c}{dt} = A\,e\,\sigma(T_a{}^4 - T_c{}^4) \qquad (2)$$

or

$$\frac{\dfrac{mc}{f}\,\dfrac{dT_c}{dt}}{e\,\sigma(T_a{}^4 - T_c{}^4)} = A \qquad (3)$$

where A is a proportional factor that has a value of 1 if the assumption that the convective transfer is negligible is correct.

The specific absorption e of 0.9 and the data from the fires were substituted in equation 3 and the average value of A was found to be 1.0 (±0.1) for all except one fire. If the assumption, that the heat transfer by convection is negligible, was wrong, then the value of A would be greater than 1.0. The data from one of the large fires actually yielded a value of 1.5, indicating that in this instance the convective heat transfer was equal to one-half the radiation heat transfer. It is assumed that in this instance either there were errors in the measurements or some turbulence at the position of the cylinders greatly increased the convective heat transfer.

The calculations given above indicate that the convective heat transfer is, to be conservative, less than 20 percent of the total heat transfer from the flame of the fire to the calorimeter.

ACKNOWLEDGMENT

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DEPARTMENT OF THE AIR FORCE
AIR FORCE INSTITUTE FOR ENVIRONMENT, SAFETY AND
OCCUPATIONAL HEALTH RISK ANALYSIS (AFMC)
BROOKS AIR FORCE BASE TEXAS

10 April 2003

MEMORANDUM FOR LARRY DOWNING
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SUBJECT: Changing the Distribution Statement on a Technical Report

This letter documents the requirement for DTIC to change the distribution statement from "~~B~~ C" to "A" (Approved for public release; distribution is unlimited.) on the following technical report: AD Number ~~ADB807341,~~ SAM-4, Effects of Extreme Heat on Man-IV-Mechanism of Heat Transfer in an Open Gasoline Fire.
ADB213029

If additional information or a corrected cover page and SF Form 298 are required please let me know. You can reach me at DSN 240-6019 or my e-mail address is sherry.mcnew@brooks.af.mil.

Thank you for your assistance in making this change.

SHERRY Y. MCNEW
AFIERA STINFO Officer

cc:
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